Semi-Annual Progress Report

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Task Objectives

The objectives of the last six months were:

- Deliver next version of chlorophyll fluorescence efficiency code to Miami
- Prepare manuscript on phytoplankton fluorescence and primary productivity
- Conduct chemostat experiments on fluorescence
- Participate in International Ocean Color Coordinating Group meeting on ocean color calibration and validation
- Prepare bio-optical equipment for Hawaii JGOFS mooring
- Present results on bio-optical time scales as estimated from Lagrangian drifters
- Acquire and ship three bio-optical drifters to New Zealand for deployment during first U.S. JGOFS Polar Front survey
- Participate in Japanese GLI workshop
- Continue development of advanced data system browser
- Continue to review plans for EOSDIS and assist ECS contractor

Work Accomplished

Algorithm Development

Our first activity is based on delivery of code to Bob Evans (University of Miami) for integration and eventual delivery to the MODIS Science Data Support Team. As we noted in our previous semi-annual report, coding required the development and analysis of an end-to-end model of fluorescence line height (FLH) errors and sensitivity. This model is described in a paper in press in *Remote Sensing of the Environment.* Once the code was delivered to Miami, we continue to use this error analysis to evaluate proposed changes in MODIS sensor specifications and performance. Simply evaluating such changes on a band by band basis may obscure the true impacts of changes in sensor performance that are manifested in the complete algorithm. This is especially true with FLH that is sensitive to band placement and width. The error model will be used by Howard Gordon (Miami) to evaluate the effects of absorbing aerosols on the FLH algorithm performance. Presently, FLH relies only on simple corrections for atmospheric effects (viewing geometry, Rayleigh scattering) without correcting for aerosols. Our analysis suggests that aerosols should have a small impact relative to changes in the quantum yield of fluorescence in phytoplankton. However, the effect of absorbing aerosol is a new process and will be evaluated by Gordon.

Delivery of CFE and FLH Code

A "C" version of the CFE algorithm has been delivered to Robert Evans at the University of Miami. Test data based on our measurements from near-surface ocean drifters was also delivered. The code relies on FLH and the MOD22 product by Ken Carder, photons absorbed by phytoplankton in the upper ocean (ARP). The algorithm is straightforward, relying on a conversion of FLH into photons and then calculating a ratio of FLH and ARP. However, the basic ARP calculation is a new product, and we will conduct several studies before launch to evaluate the robustness of the CFE product.

The Version 1 FLH and CFE algorithms are standalone products. However, because of their close coupling, the Version 2 code will calculate both products together. This algorithm will be delivered at the end of the year for the V2 delivery to SDST. This version will also include a complete suite of quality assurance flags that will be used as part of the "in-line" processing at the DAAC.

Extension of FLH to Primary Productivity

At this point in time, the basic fluorescence products for MODIS are well in hand. However, the strength of the fluorescence measurement is its use in primary productivity estimates. The present productivity models being developed for MODIS are suitable for large space and time scales. Such products are suitable for many scientific applications, but there are equally important applications that require productivity on shorter time and space scales. To estimate productivity on these scales requires access to some measure of the photosynthetic state of the phytoplankton. Our field results (discussed below) have suggested an approach to estimating the quantum yield of fluorescence, which is related to the quantum yield of productivity. Much of our research has been focused on building the fundamental basis of the next generation productivity algorithms that will use MODIS fluorescence observations.

The first step in this process was the development of a manuscript based on our previously reported observations in Drake Passage. We deployed two drifters in the Southern Ocean in austral summer 1994. Each drifter collected bio-optical data as well as temperature. One drifter was trapped in a cyclonic eddy for 40 days. These data have now been analyzed and a manuscript submitted to *Science*. We were able to estimate the product of the quantum yield of fluorescence and the cross-sectional area of Photosystem II based on the ratio of fluorescence to chlorophyll. Using some simple assumptions regarding absorption cross-section, we were also able to simplify this relationship to determine fluorescence quantum yield alone. By estimating fluorescence quantum yield, we showed a strong correlation between the photoadaptive state of the phytoplankton and the strength of upwelling within the eddy. These episodic pulses probably injected iron into the upper layer of the eddy, thus reducing nutrient stress and increasing primary productivity. These are the first data to show a repeated, transient response of phytoplankton productivity to iron injection in a natural environment. From an EOS perspective, these data show that the fluorescence bands on MODIS may be used quantitatively to assess the photoadaptive state of phytoplankton in the upper ocean which will form the basis of the next-generation primary productivity algorithms. The quantum yield tended to fall into one of two regimes, thus suggesting that a relatively simple model of primary productivity may be developed from MODIS observations of the fluorescence/chlorophyll ratio.

The second phase of this activity involves phytoplankton culture experiments using chemostats. As reported in the previous semi-annual report, these experiments will follow the protocols established in collaboration with Dr. Paul Falkowski (Brookhaven National Lab). Several species of phytoplankton will be grown under different nutrient regimes, and the relationship between fluorescence quantum yield and primary productivity will be established. This research is directly applicable to MODIS as it will establish the basis of productivity algorithms through a direct understanding of phytoplankton physiology as opposed to purely empirical correlation analyses. We will also be able to quantify the error budget associated with the algorithm. The chemostats have been built and are now running. A graduate student, Daniel Diehl, is planning to use this research as the basis of his Master's thesis. We expect to have the first results in early autumn. However, the full set of experiments has been delayed due to the late delivery of the Fast Repetition Rate (FRR) fluorometer from Chelsea Instruments. The FRR fluorometer will provide rapid assessment of the photosynthetic capacity of the phytoplankton and is an essential tool for the chemostat experiments.

The results of these fluorescence and productivity studies (including analysis of the bio-optical drifter data from the California Current) will be presented at the SPIE Ocean Optics meeting Halifax, NS this autumn.

Algorithm Validation Activities

There are two related approaches in our validation activities. First, we are measuring sun-stimulated phytoplankton fluorescence in a wide variety of oceanographic conditions which will provide quantitative limits on the variability of FLH and CFE and the relationship of this variability to environmental and physiological factors. As noted in our FLH error analysis, the most significant challenge in FLH and CFE will be its interpretation in the context of phytoplankton physiology. Second, we are quantifying the time and space scales of variability of fluorescence and productivity. These estimates will be used to develop quality assurance tests as well as to develop rigorous tests for product validation. As noted in the draft EOS Validation plan, this information is essential for eventual users of EOS data so that they can evaluate the suitability of data products for various scientific applications.

A similar approach was taken at the meeting on ocean color calibration and validation held in Toulouse, France. This meeting was sponsored by the recently established International Ocean Color Coordinating Group (IOCCG) which operates under the auspices of CEOS. This meeting was designed to bring together the international ocean color community to develop a coordinated plan, building on the NASA SIMBIOS program. I participated in this meeting, and I presented results from our bio-optical drifter studies. These show how relatively inexpensive moorings and drifters could be used to study scales not amenable to satellite observations as part of the validation process. A similar meeting was also held by the Joint U.S./Japan Workshop on Ocean Color in La Jolla. This meeting focused primarily on the upcoming launches of SeaWiFS and OCTS as well as MODIS and GLI.

One of the challenges in validation of EOS oceans products is the need to leverage field opportunities with other programs in order to keep costs manageable. Our next field campaign will be a survey of the productive nearshore waters off the Olympic Peninsula in Washington. Surveys of chlorophyll, nutrients, productivity, and bio-optics will be conducted within 10 km of the coast, a region of the ocean that is only occasionally sampled. Although the science focus is on the coupling between the shoreline ecosystem and the coastal ocean, this cruise will provide a unique opportunity for us to sample a very productive ecosystem.

A longer term opportunity is presented by the U.S. JGOFS time series station in Hawaii (the Hawaii Ocean Time-series or HOT site). As we discussed in a previous report, we have developed and built a bio-optical sensor for deployment at HOT. This site is complementary to the activities underway at the MOBY site which is run by Dennis Clark. HOT is visited regularly and a full suite of biogeochemical measurements is made. Our optical equipment is not designed for sensor calibration, but is instead focused on algorithm development (primarily productivity) and validation. We have assembled the components to install a bio-optical sensor at the JGOFS Hawaii Ocean Time-Series station north of Oahu. The deployment of this mooring has been delayed until fall because of scheduling difficulties encountered at the University. of Hawaii. We have also ordered the components necessary to assemble a second bio-optical sensor. The upper sensor will be set at 30 m depth and the second sensor will be at 100 m. This summer we will participate in a cruise from HOT to the CLIMAX station, another long-term observing site in the central oligotrophic gyre of the Pacific.

Although such partnerships are an excellent way to improve scientific return and to reduce costs, one of the downsides is the inability to control schedules and activities. We have had our bio-optical mooring equipment ready for deployment since the beginning of the year, but have had to repeatedly delay because of ship scheduling and personnel issues that are out of our control. However, in the long run, such delays are minor compared with the eventual return.

Our second approach is to provide quantitative estimates of the scales of bio-optical variability, especially in the area of fluorescence. As reported earlier, there are significant differences onshore and offshore, reflecting changes in the scales of the physical environment. These results were presented at the AGU/ASLO Ocean Sciences meeting in San Diego. A complete analysis is the subject of a manuscript in preparation.

Similar bio-optical drifters will be deployed in the upcoming U.S. JGOFS program in the Southern Ocean known as AESOPS (Antarctic Environment Southern Ocean Process Study). Part of AESOPS will focus on mesoscale variability in the Antarctic Polar Frontal Zone and its role in governing biogeochemical fluxes. The bio-optical and conventional drifters will be equipped with GPS units to provide estimates of near-surface convergences and divergences associated with frontal meanders. These properties will be compared with an array of moored bio-optical sensors and high-resolution SeaSoar surveys of the biological and physical environment. These activities will largely be funded by the National Science Foundation, but MODIS funding has been used to acquire six bio-optical drifters to continue our algorithm validation activities at the high latitude Polar Front. Three of these drifters will be deployed this September at the Polar Front. The remaining three will be deployed next year in the main AESOPS field season. The FRR fluorometer will also be used during the next field season for assessments of the relationship between photosynthesis and fluorescence.

GLI Activities

The Japanese space agency, NASDA, released a Research Announcement soliciting proposals for algorithm development for GLI. This sensor is similar to MODIS and will launch in mid-1999 on ADEOS-II. I was the lead for the MODIS Oceans team (MOCEAN) response to the RA. Our proposal was accepted by NASDA this spring, and I attended the first ADEOS-II workshop on GLI and AMSR. MOCEAN will provide NASDA with copies of the MODIS oceans algorithms that we submit to the MODIS SDST. We will compare the equivalent MODIS data products with those from GLI. We expect to receive copies of the GLI algorithms as well. We will also pursue techniques to blend these two data products together and participate in join validation and calibration activities to support data synthesis. Our plan has evolved to include the hiring of a full-time person at OSU to act as the "point person" for MODIS/GLI integration for the oceans data products.

There are clearly many challenges ahead in the use of GLI data. Although the basic design is similar to MODIS (with similar stray light problems), GLI is a tiltable sensor and lacks an SRCA. The planned pre-launch characterization tests are also much reduced compared to MODIS. Some of the bands are in slightly different positions. However, there is a strong commitment on the part of Japan (including funding) to forge strong ties between the MODIS and GLI teams. We agreed to schedule joint meetings between MOCEAN and GLI as well as to share updates on sensor and algorithm progress.

EOSDIS Plans

Beyond algorithm development and validation, we have also invested in infrastructure necessary to support data analysis and validation activities. These include the following specific tasks.

Advanced Networking

As noted in our Quarterly Progress Report, we completed tests on the use of Asynchronous Transfer Mode (ATM) networks for data delivery to the desktop. EOSDIS is planning to deploy some ATM circuits for long-haul data delivery between some centers, but the power of ATM is its ability to run clear down to the desktop. However, our first test showed that there are significant issues in scalability, especially in the number of simultaneous users that can be accommodated on the network. The next stage of testing will be to move towards more powerful servers and clients, based on Digital Equipment Corp. Alpha machines. These tests are being conducted with Adaptec Corp.

Information Systems Development

We have completed the linkage of our data base of bio-optical measurements (from both drifters and moorings) with Web browsers. Using both home-grown and off-the-shelf components, the data search and retrieval system is integrated directly with data display and analysis software. We will continue to expand upon this base functionality over the coming months. We have also completed a prototype data base to handle satellite imagery. This includes tools to overlay directly ship and drifter tracks on the imagery and to extract the digital values from the imagery for comparison with the in situ measurements. Our present system uses both Java (Sun Microsystems) and ActiveX (Microsoft) applets for analysis and presentation. We have also developed data splining and statistical applets that will become part of the data browser framework.

The rapid developments in the Web browser market and with the continuing evolution of distributed software objects based on Java or ActiveX make for interesting times. However, these technologies are clearly suitable for the development of distributed data systems, perhaps even beyond what is envisioned for the EOSDIS federation. Their first application is clearly to share in situ data as part of the MODIS validation activities.

Anticipated Future Actions

- Revise the Algorithm Theoretical Basis Document (ATBD) and participate in panel review. The revised ATBD will include more detailed plans for validation as part of the overall EOS validation activity. We have also revised our CFE approach since the original ATBD, and we will also outline our results and approach for a new primary productivity data set. The latter will be a post-launch product.
- Develop quality assurance plan and quality flags for our data products. A first set will be delivered to Miami and compared with other products, especially where there are dependencies between FLH and CFE and other products.
- Contribute to and review the MOCEAN validation plan.
- Complete manuscript on bio-optical scales.
- Complete analysis of fluorescence quantum yields in the California Current. Compare with Southern Ocean results. Present results at SPIE Ocean Optics meeting.
- Combine CFE and FLH algorithms into single code. Incorporate in-line processing flags. Submit to Miami as Version 2 algorithm.
- Hire postdoctoral level person to serve as point of contact for MOCEAN and GLI activities. Deliver V1 code to GLI oceans team and begin to define integration issues.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant problem has again been unforeseen delays in receiving the Fast Repetition Rate fluorometer. However, we have now determined a firm delivery date of spring 1997. The other delay has been the deployment of the mooring at Station Aloha north of Hawaii. We now have a deployment date of November 1996.

The piecemeal distribution of funds have made it difficult to budget and plan procurements of larger pieces of equipment.

We are concerned about the deletion of prelaunch characterization tests for MODIS. This may make it extremely difficult to deliver science-quality data products at launch. We strongly recommend that the EOS Project maintain these essential tests.